Application of the MCMC Method for the Calibration of DSMC Parameters to NASA EAST Results for Ionizing, Radiating Hypersonic Flows

Completed Technology Project (2014 - 2018)

Project Introduction

The reentry of a vehicle into a planetary atmosphere creates extreme Mach number conditions which produce a weakly ionized plasma and radiation. The greatest challenge for a vehicle flying at hypersonic speeds is the heat generated in the shock layer. Predicting the effects of hypersonic heating is integral to heat shield design, but experimental tests are costly and have issues of reliability since it is extremely hard to match flight conditions. Thus, numerical models have been established that simulate reentry conditions and quantify the effects of hypersonic flow. Substantial progress has been made in the development of sophisticated numerical methods, but many of these models have not been validated nor their uncertainties quantified. During the initial phases of reentry into Earth's atmosphere, for example, a vehicle passes through the rarefied upper atmosphere. Even in the rarefied regime, heat soaking occurs and spacecraft dynamics and radio communications remain critical. Although peak heating in Earth's atmosphere generally occurs at lower altitude in the continuum region, this may not be the case for hypersonic entry on other planets. Therefore, numerical models such as the direct simulation Monte Carlo (DSMC)1 technique have been developed that can model rarefied regimes. To model a hypersonic reentry problem accurately, non-continuum methods must resolve a non-equilibrium flow and account for high speed molecular collisions, chemical reactions, electronic excitation, ionization, and radiation. The numerical techniques that model these phenomena require experimental calibration of a number of parameters. Many of these parameters cannot be accurately measured under the extreme conditions of hypersonic flows, and are instead inferred from lower speed experiments. Much of the error in the non-continuum hypersonic numerical methods stems from inaccuracies in these input parameters. In order for these numerical models to be utilized reliably, one must quantify the uncertainty resulting from errors in experimental measurements of model parameters and the extrapolation to the hypersonic scenario of interest. This program will utilize the unique NASA Ames Electric Arc Shock Tube (EAST) data in combination with a state of the art hypersonic shock tube DSMC code linked to a radiative transport code to obtain calibrated DSMC parameters through sophisticated statistical analysis methods. Among goals for this project are to: 1. Adapt the DSMC code by adding ionization to the current version. 2. Link the DSMC code to a line-by-line radiation solver and compare results to the unique NASA Ames EAST results. 3. Perform a sensitivity analysis of the linked DSMC/Radiation results. 4. Calibrate the essential DSMC parameters to the NASA EAST data using The University of Texas QUESO MCMC code. 5. Refine the model and recalibrate parameters to improve the prediction of hypersonic flows in space vehicle reentry scenarios. The results of this project would represent the first time that hypersonic DSMC parameters have been calibrated to experimental data in such a systematic way. By then quantifying the uncertainty of the physical parameters, we can understand the range of errors in the DSMC model. Furthermore, since many of the Arrhenius reaction

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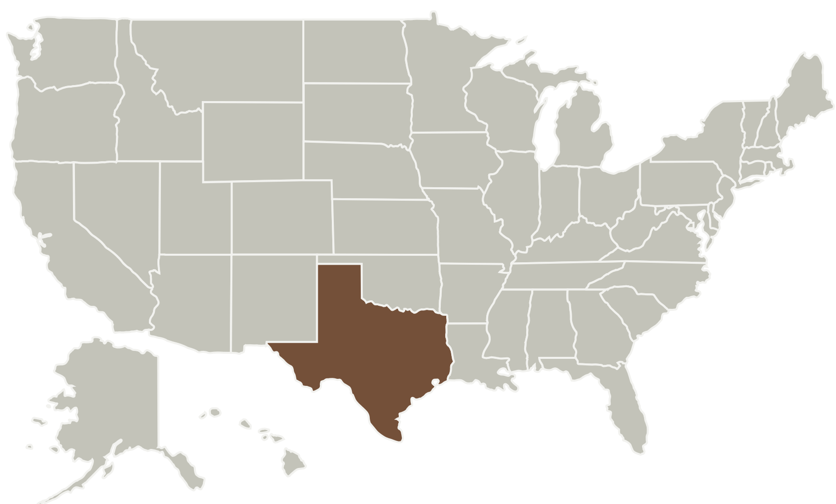
rates used in the TCE model have a high uncertainty, the calibrated parameters should close the loop between experiments and simulation and assist experimentalists in identifying which parameters are critical for future investigation. This is important for reentry vehicles because an improved understanding of hypersonic heating can result in the advancement of thermal protection system technology.

Anticipated Benefits

This project aims to improve numerical models for predicting the effects of hypersonic heating, which is integral to heat shield design.

Primary U.S. Work Locations and Key Partners



Organizations Performing Work	Role	Type	Location
The University of Texas at Austin	Lead Organization	Academia	Austin, Texas

Primary U.S. Work Locations
Texas

Organizational Responsibility

Responsible Mission Directorate:

Space Technology Mission Directorate (STMD)

Lead Organization:

The University of Texas at Austin

Responsible Program:

Space Technology Research Grants

Project Management

Program Director:

Claudia M Meyer

Program Manager:

Hung D Nguyen

Principal Investigator:

David I Goldstein

Co-Investigator:

Kyle J Higdon

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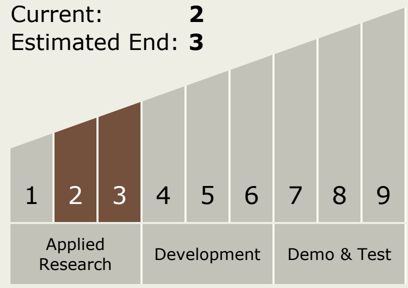
Project Website:

https://www.nasa.gov/directorates/spacetech/home/index.html

Technology Maturity (TRL)

Start: **2**
Current: **2**
Estimated End: **3**



Technology Areas

Primary:

- TX01 Propulsion Systems
  └ TX01.3 Aero Propulsion
    └ TX01.3.5 Turbine Based Jet Engines

Target Destination

Foundational Knowledge